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Nearshore assessment of wave energy resources in central Chile (2009–2010)

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ABSTRACT

The goal of this work is to estimate nearshore wave energy resources in central Chile with high spatial resolution. Due to the lack of in situ measurements a suite of numerical models are used to assess the wave energy between 2009 and 2010. We compare the effects of different wind forcing reanalysis, particularly CFSR and ERA-Interim, and physics parametrizations on numerical simulations of the nearshore wave energy fluxes near Valparaiso (33°S), central Chile. For this we utilize WAVEWATCH III®, an open source community spectral wave model, configured with a high resolution unstructured grid (200–400 m at the coast). Our results show a difference of 3 kW/m in wave power estimations when using different wind reanalysis, and less a difference of less than 0.5 kW/m when adding the triad wave interactions term. Statistical indicators calculated using buoy and altimeter data for comparison favor the use of ERA-Interim winds and including triad wave interactions. For the Valparaiso region, the area south of Punta Curaumilla was confirmed as a hot spot of wave energy (4–5 MW/yr), with the most energetic and frequent sea state described by Te of 9–11 s and H_s 2.5–3.5 m.

1. Introduction

Energy production in Chile during 2011 consisted on 63% thermoelectric, 34% hydroelectric resources, and 3% non-conventional renewable energy (NCRE) sources [1]. More than 60% of the energy demand in Chile is covered with imported resources due to limited resources of gas, oil, and coal. The cost of electrical energy for the industry is one of the highest in Latin America. The future availability of traditional energy sources such as coal-powered thermoelectric plants might not be sufficient to cope with the increasing needs of the mining industry in the northern part of the country, or be able supply remote off-grid populations such as those in southern Chile's fjord area. In response to this, the legal Act 20.257 established a legal framework to define financial incentives for NCRE. The government's initiatives state that by 2025, 45% of the energy should come from NCRE, such as solar, wind, wave and tidal energy [2]. The availability of NCRE has been subject to several recent studies [3–5]. These studies demonstrate that wave energy is an important alternative, relatively to solar, wind, and hydrology options, due to the geographical availability, and a wave climate dominated by swell produced across the Pacific Ocean [4].

With over 4000 km of exposed coast, wave energy reports in Chile have described a potential of 169 GW [5] using omnidirectional power estimations, 240 GW [4], and 194 ± 11 GW [6], using global results from NOAA's WAVEWATCH III® (hereafter WW3) model. For the Valparaiso area (Fig. 1), the wave energy resources have been estimated being 41 kW/m in a study by the National Hydraulic Institute (NHI), 40–60 kW/m in (http://aw-energy.com), and 35.8 kW/m using a Pacific WW3 1° run and STWAVE to do the spectral transfer of waves towards shallow water [4]. Another study using SWAN and a WW3 hindcast found a maximum annual mean of 126 kW/m for Punta Curaumilla, near Valparaiso [7]. Global wave energy studies have also described an increasing N–S pattern with 40–50 kW/m for central Chile [6].

WW3 is a third-generation spectral model that describes the development of wind waves and their propagation from deep to

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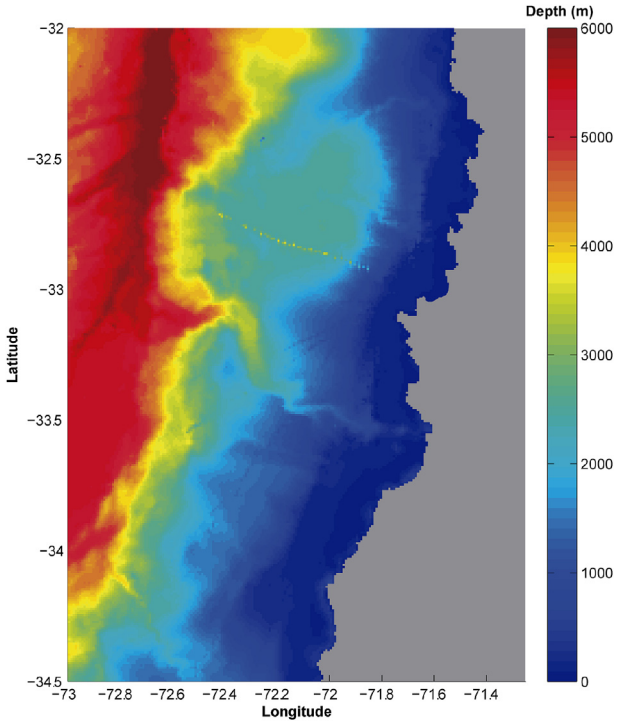

Fig. 1. Coastline and bathymetry for the central Chile area.

shallow waters by resolving the action balance equation for the evolution of the wave spectra [8,9]. Recent developments in WW3 physics have improved swell dissipation, wave breaking, shoreline reflection, and non-linear interactions [10–12]. Also recent is the use of unstructured grids as an alternative to grid refinement with nested domains [13]. This an important step towards resolving wave parameters in the nearshore area, which is critical to the technical selection of Wave Energy Converters (WEC) [14]. Nearshore wave energy availability has been characterized before by nesting different models to describe the wave transformations from the open ocean into intermediate and shallow waters. These studies have used models such as SWAN [7,15,16], STWAVE, MIKE21 SW [17], or REF/DIF-1 [18], forced by

Table 1
Main details of WW3 configuration file *switch* for CFSR and ECMWF runs, where wind forcing was obtained from CFSR and ERA-I. Configuration E_TR1 uses ERA-I winds and had activated the switch related to the wave triad interaction (in bold), using the **TR1** option instead. For further details on the meaning of each option, see the Refs. [9,10].

PR3	UQ	REF1	IOS2	ST4	STAB0
FLX0	NL1	BT4	DB1	MLIM	BS0
TR0	SEED	WNX1	WNT2	CRX1	CRT1

Table 2
Evaluation of significant wave height, H_s [m]. Model versus buoy data. Statistical indexes used are: normalized root mean square error (NRMSE), normalized bias (NBIAS), scatter index (SI), slope of linear adjustment (Slope), and Spearman's correlation coefficient (R^2). Calculated values were significant ($p < 0.001$). N = 3252. Optimal values in bold.

Case	NRMSE (%)	NBIAS (%)	SI (%)	Slope	R^2
CFSR	0.19	−0.13	0.14	1.11	0.8
ECMWF	**0.15**	**−0.09**	**0.12**	1.07	**0.9**
E_TR1	**0.15**	**−0.09**	0.13	**1.06**	**0.9**

global configurations of WW3 or WAM [19]. In this study we implement an unstructured grid within WW3 framework to study wave energy availability in the nearshore Valparaiso Bay, Chile.

The goal of this work is to estimate wave energy resources for the nearshore area of central Chile during 2009–2010 using a high spatial resolution WW3 configuration based on an unstructured grid (Fig. 2). This model resolves the offshore and nearshore waves simultaneously and is forced with a global WW3 model, using wind forcing from two different reanalysis, and different physics options. We compare the results with directional measurements from a single buoy, and quality controlled altimetry data from multiple satellite missions. We choose to simulate only a period between 2009 and 2010 due to the availability of one of the few year-long buoy records in the region. Wave parameters from buoy measurements in Chile are scarce, compared with many other countries. This work is a first step towards the development of the wave modeling capabilities near Chile utilizing the unstructured version of WW3 and the improved physics to reproduce the wave conditions nearshore.

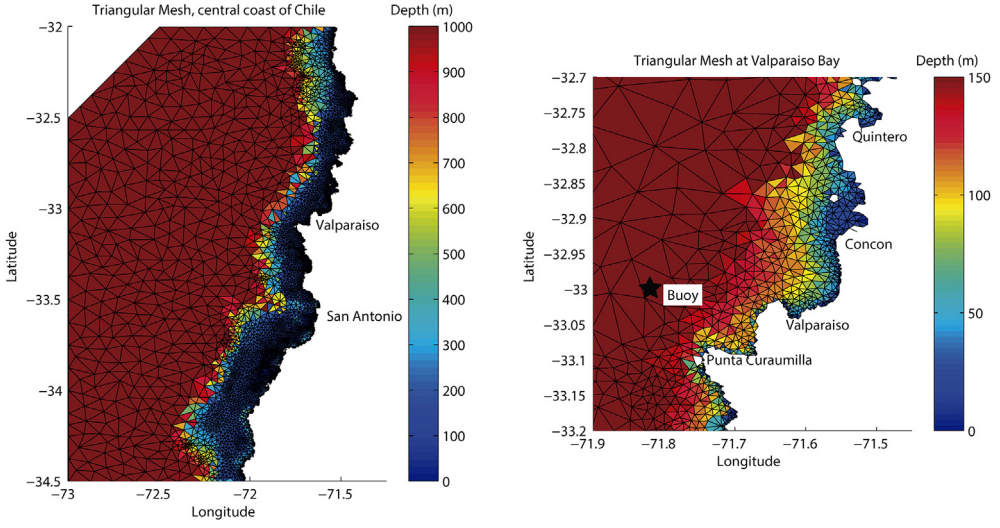

Fig. 2. Model grid for the central Chile model with zoom in Valparaiso area.